Appendix F

Performance Tests for Computerized Tomographic Units

A. General Requirements for Computed Tomography Equipment

1. Table Loading

a. Purpose: To verify manufacturer's weight loading specifications for the patient support device.

b. Regulations: Refer to manufacturer's specifications.

c. Equipment: Weights and/or persons totaling the manufacturer's loading specifications.

d. Procedure: Distribute specified weight over table top in proportion to normal weight distribution. Check full range of vertical and horizontal motion. Record maximum weight and range of motion. Do not load table beyond manufacturer's specification.

e. Interpretation of results: If table loading requirements do not meet manufacturer's specifications consult a qualified service engineer.

2. Laser Light Alignment

a. Purpose: To ensure that laser lights are properly aligned with the scan slice

b. Regulations: Manufacturer's specification or $\pm$ 2 mm.

c. Equipment: Ready pack film, pin/needle, and ruler.

d. Procedure:

(1) Align the edges of a prepackaged film sheet to the edges of the acrylic backing plate. Secure with tape.

(2) Secure film/plate with tape to table top along long axis of table and raise table to head position. If both internal and external alignment lights are provided, position plate so that both lights are visible on film surface if possible.

(3) Turn on internal alignment light and mark light location on film by piercing film pack with pin at several points along the illuminated line. Repeat for the external light, using a different pinhole pattern to allow later identification of the two lasers.

(4) Expose film at inner light location, using narrowest slice setting with standard head technique. For external light, move table to scan position under software control and repeat scan.

e. Interpretation of results:

(1) After processing films, recreate the laser lines using the localization light hole indicators on the film.

(2) Measure the separation between the lines drawn from the holes in the processed film to the middle of the radiation slices.

(3) In the absence of manufacturer's specifications, the error should not exceed $\pm$ 2 mm.

3. Table Positioning

a. Purpose: To ensure that table movement and localization is accurate.

b. Regulations: Manufacturer's specifications or $\pm$ 1 mm.

c. Equipment: Ruler.

d. Procedure: Tape a ruler to the fixed portion of the patient support assembly. Make a mark on the table adjacent to the tape measure. Move the table both in and out of the gantry to predetermined distances. Record the actual and selected distances traveled (typically 1, 10 and 40 cm.).

e. Interpretation of results: The table should move smoothly and accurately to within 1 mm of target in either movement direction. Consult a qualified engineer if the requirement is not met.

4. Table Incrementation

a. Purpose: To ensure that table incrementation is accurate.

b. Regulations: Manufacturer's specifications or ± 1 mm.

c. Equipment: AAPM or CTDI phantom, ready pack film and ruler.

d. Procedure:

(1) Attach a piece of ready pack film to the phantom. Place the phantom on the patient support assembly. Expose the film using a 5 slice set of 5 mm thick slices on 5 mm centers.

(2) Develop the film and measure the distance between the centers of each set of adjacent density bands.

e. Interpretation of Results: The average distance measured between adjacent density band centers should equal the interslice movement ± 1 mm. If they are not consult a qualified service engineer.

5. Table/Gantry Alignment

a. Purpose: To ensure proper alignment of the table and gantry isocenter.

b. Regulations: Manufacturer's specifications or ±5 mm.

c. Equipment: Ruler.

d. Procedure:

(1) Using the laser light, raise the scanning table until the lateral lasers intersect the horizontal plane.

(2) Insert the table into the gantry opening.

(3) Scan the table using the standard head technique. Using the electronic ruler and grid, project the distance from grid center to right and left table edges onto the grid.

(4) Compare the two distances and determine the difference between them.

(5) Calculate misalignment as half the difference between the two measurements.

e. Interpretation of Results: Misalignment of the two table edges and isocenter should be ≤ 5 mm. If it is not consult a qualified service engineer.

6. Gantry Tilt Angle

a. Purpose: To ensure the gantry tilt angle is within ± 3 degrees of the nominal setting.

b. Regulations: Gantry tilt angle should be within ± 3 degrees of the nominal setting.

c. Equipment: Ready pack film (optional) and protractor.

d. Procedure: This test may be conducted either by a mechanical method or using radiation.

(1) Mechanical method: Place a protractor on the front face of the scanner. Note the angle of the protractor. Tilt the gantry to predetermined forward and backward angles. (extreme forward, extreme backward and zero). At each gantry stop, record the measured vs. indicated gantry angle.

(2) Radiation method: Place a piece of ready pack film placed along the sagittal plane, perpendicular to the scan plane. Make an exposure using a 1 mm slice thickness (or smallest available) at each gantry stop. Develop the film. Measure and record the actual gantry angles.

e. Interpretation of Results: The gantry tilt angles determined by either the mechanical or radiation method must be within ± 3 degrees of the nominal setting. If not consult a qualified service engineer.

7. Exposure Slice Width

a. Purpose: To ensure that the exposure slice width is accurate.

b. Regulations: The exposure slice width should be within ± 1 mm of the nominal slice width setting.

c. Equipment: Phantom, ready pack film and ruler.

d. Procedure:

(1) Place a phantom (AAPM or CTDI) on the patient support assembly. Attach a piece of ready pack film to the phantom. Run a series of CT slices. Increment table and repeat for other slice widths.

(2) Develop the film. Measure and record the distance from the leading edge to the outside edge of the set of contiguous slices. Divide by the number of slices in the set. Record this value as the average slice width. The smallest slice width should be carefully evaluated. (i.e., a table incrementation of 1 mm with a 1 mm slice width may cause the slices to overlap since most 1 mm slices are actually closer to 1.5 mm). If this occurs repeat scan with a larger table spacing.

e. Interpretation of Results: The exposure slice width should be within + 1 mm of the nominal setting. In general, slice width is not adjustable. Further evaluation of slice width will be conducted with a phantom and is explained in the slice sensitivity section. A service engineer should be consulted if both evaluations indicate the slice width is not within ± 1 mm or manufacturer's specifications.

8. Projection to Scan Accuracy and Artifact

a. Purpose: To evaluate projection to scan accuracy and artifacts.

b. Regulations: Projected image should be within ± 1 mm of scan location. There should be no "star" artifact present.

c. Equipment: Metal marker such as radiopaque BB.

d. Procedure:

(1) Place a phantom on the patient support assembly. Place a radiopaque marker on the phantom. Position the assembly to scan the marker.

(2) Scan the phantom with a sagittal axis scan centered on the marker. Then scan the phantom with an axial scan centered on the marker using the smallest available slice width.

(3) Review the sagittal scan. Measure and record the distance between the marker and the "0.0" on the display. Review the axial scan to ensure that the marker is present. (If not adjust the table and rescan). Record whether a "star" artifact is present.

e. Interpretation of Results:

(1) The marker should be within ± 1 mm in the projected image. A combination of laser light misalignment and projection to scan misalignment may result in unsatisfactory scanner performance. A qualified service engineer should be consulted to correct the misalignment.

(2) A distinct "star" artifact should not be present when using the radiopaque skin markers. This would result in poor image quality for any patient that required their use. (A small artifact will most likely be present). Consult a qualified service engineer if the artifact interferes with clinical image quality.

9. Image Noise

a. Purpose: To ensure that an image of a phantom filled with a uniformly attenuating material shows minimal noise over the field of view.

b. Regulations:

(1) In the absence of manufacturer's noise specifications see section e. below.

c. Equipment: Uniform water phantom. Prepare phantom as follows:

(1) Ensure all water phantom inserts to be used are placed in the water phantom before filling.

(2) Prior to use, the water phantom should be nearly filled with deionized water, following manufacturer's instructions.

(3) Trapped air bubbles should be dispelled by mechanical agitation.

(4) The water filled phantom should be allowed to "settle" overnight.

(5) After a settling period, the phantom should be filled completely and all remaining air displaced.

d. Procedure:

(1) Perform calibration scan according to manufacturer's recommendations. This can be performed by the service engineer prior to physicist's evaluation.

(2) Center water phantom in the gantry opening using phantom brackets if available. Align a section of phantom without inserts or test tools (just water) for scanning (or use manufacturer's noise/uniformity phantom).

(3) Scan phantom using the desired parameters. Save the image. Repeat using other FOVs and reconstruction algorithms, as necessary.

(4) Using the statistics tools, create a circular ROI of approximately 100 mm^2. Measure the mean pixel and standard deviation values for ROIs placed at the image center and at 3, 6, 9 and 12 o'clock positions at 70% of the radius.

e. Interpretation of Results: In the absence of manufacturer's specifications, noise (standard deviation) should be < 4 CT numbers in standard head and body modes and < 35 CT numbers in the high resolution mode. Consult a qualified service engineer if noise is not within these specifications. Excessive noise will effect low contrast image quality.

10. Field Uniformity

a. Purpose: To ensure that an image of a phantom filled with a uniformly attenuating material shows adequate signal uniformity over the field of view.

b. Regulations: Manufacturer's specifications or section e. below. (AAPM specification is 5 CT numbers).

c. Equipment: Uniform water phantom.

d. Procedure: Utilize the previously recorded average CT numbers for each ROI for each scan mode.

e. Interpretation of Results: In the absence of manufacturer's specifications, uniformity (i.e., maximum variation between the mean CT numbers for any two ROIs in a single study slice) should not exceed 5 CT numbers, preferably within 2 CT numbers. If uniformity is not within specifications contact a qualified service engineer.

11. CT Number Calibration

a. Purpose: To ensure that the CT numbers associated with air and water are accurate..

b. Regulations: In the absence of manufacturer's specifications the water ROI should be 0 $\pm$ 1.5 HU and the air ROI should be 1000 $\pm$ 3 HU in standard clinical mode. For other modes the ROI should be $\pm$ 3 HU.

c. Equipment: Water phantom (head and/or body) and previously scanned data from noise images.

d. Procedure: Utilize the previously recorded average CT numbers for the center ROI and air ROI for each scan mode.

e. Interpretation of Results: If the CT number does not meet specification contact a qualified service engineer for adjustment.

12. Linearity

a. Purpose: To ensure CT number linearity for materials with a range of linear attenuation coefficients.

b. Regulations: Manufacturer's specifications or section e. below lists AAPM recommendations.

c. Equipment: Performance phantom linearity insert.

d. Procedure:

(1) Center the phantom with the linearity test tool in the gantry opening and align with the table. Move the section of the phantom with the test object to the scan plane.

(2) Scan the insert. Using the ROI function, determine the mean CT number of each pin and the water background. Save the annotated image.

e. Interpretation of Results:

(1) Plot the mean CT numbers for each material as a function of its linear attenuation value.

(2) Note that the linear attenuation values are dependent on the effective energy of the beam (should be determined during acceptance).

(3) In the absence of manufacturer's specifications, the AAPM recommends "that any CT number mean value should not deviate by more than two times the standard deviation from a best fit straight line describing the relationship of CT number mean values to linear attenuation coefficient over the ranger of polyethylene to Plexiglas.

13. Contrast Scale

a. Purpose: To ensure contrast scale of CT numbers.

b. Regulations: Manufacturer's specifications or section e. below lists AAPM recommendations.

c. Equipment: Performance phantom uniform water section.

d. Procedure:

(1) Center the phantom with the water section in the gantry opening and align with the table. Move the water section of the phantom to the scan plane.

(2) Scan the insert. Using the ROI function, determine the mean CT number of air outside the phantom and the water section. Save the annotated image.

e. Interpretation of Results:

(1) Plot the mean CT numbers for the water and the air as a function of its linear attenuation value.

(2) Follow manufacture specifications and track over time.

14. Low Contrast Sensitivity

a. Purpose: To ensure appropriate image contrast sensitivity.

b. Regulations: Manufacturer's specifications or section e. below., it is recommended that:

c. Equipment: Performance phantom with low contrast insert. High contrast resolution test tool is not appropriate for this test.

d. Procedure:

(1) Center phantom with contrast sensitivity insert in the gantry opening and align with the table. Move section of phantom with test object to scan plane.

(2) Scan using standard head algorithm and save the image.

(3) Using the ROI function, determine the mean CT numbers for the phantom and water background. Determine the percentage contrast using the formula:

$$\frac{|\text{CT \# background - CT\# phantom}|}{10}$$

(4) Determine the smallest array pattern visible with the naked eye. Adjust window, level and room light for best viewing.

(5) Repeat steps (2) through (4) using other algorithms, as desired.

e. Interpretation of Results:

(1) Results depend on both intrinsic contrast levels and display window and level settings. Image contrast depends on sensitivity profile width (slice thickness). Therefore, contrast comparisons among algorithms should be made using the same slice width.

(2) Refer to manufacturer's specifications, if available. In the absence of manufacturer's specifications, scanners should be able to detect:

(a) Using standard algorithm, 2.5 mm hole at 1.0 percent contrast, 3 mm hole at 0.6 percent contrast, and 6 mm hole at 0.35 percent contrast.

(b) Using low contrast mode, 2 mm at 1%, 2.8 mm at 0.6% and 4 mm holes at 0.35%.

(c) In high contrast mode, 4 mm at 1%, 8 mm at 0.6% and 13 mm holes at 0.35%.

15. High Contrast Resolution

a. Purpose: To ensure adequate image resolution.

b. Regulations: In the absence of manufacturer's specifications or section e. below.

c. Equipment: Performance phantom resolution insert.

d. Procedure:

(1) Center phantom with resolution insert in the gantry opening and align the table. Move section of phantom with resolution test object to scan plane.

(2) Scan test object using standard head and body algorithms, using an 8 to 10 mm slice width. Save images for analysis.

(3) Use the zoom function to magnify the test pattern. Determine the smallest array pattern or line pair visible using a minimal window and level resulting in optimal viewing.

(4) To evaluate resolution enhancement algorithms, repeat steps (1) through (3) using the appropriate algorithm, FOV, etc.

e. Interpretation of Results:

(1) Determine the smallest resolved test object using each scan protocol.

(2) Refer to manufacturer's specifications. In the absence of specifications from the manufacturer, the standard mode should minimally resolve the 1.0 mm test tool or 5 lp/cm while the 0.5 mm test object or 10 lp/cm should be resolved in higher resolution modes.

16. Modulation Transfer Function

a. Purpose: To ensure that the modulation transfer function (MTF) for all algorithms is established during acceptance testing procedures.

b. Regulations: The 10% and 50% MTF should be evaluated and documented for all algorithms. Refer to manufacturer's specifications for...

c. Equipment: Phantom containing high resolution wire and previous scans containing high resolution insert.

d. Procedure:

(1) Utilizing previous scans of the high resolution insert and the pixel plot function, display and print/record the pixel plot of the high resolution wire.

(2) Repeat for all scan modes.

e. Interpretation of Results:

(1) Utilizing a MTF program evaluate the pixel plots of each algorithm. Some CT scanners provide MTF evaluation software. If it is not provided contact the Department of Radiology at USUHS in Bethesda, MD for software.

(2) Since MTF evaluation is primarily conducted during acceptance testing procedures the

manufacturer should be contacted immediately if manufacturer specifications are not met.

17. Slice Sensitivity

a. Purpose: To verify that the actual width of the imaged slice meets the manufacturer's specifications.

b. Regulations: Manufacturer's specifications or section e. below.

c. Equipment: Performance phantom sensitivity profile insert.

d. Procedure:

(1) Center the phantom with sensitivity profile test tool in the gantry opening and align with the table. Move the section of phantom with slice thickness insert to the scan plane.

(2) Scan the insert using the standard head algorithm and a ten mm slice thickness. Save the image.

(3) Set window to minimum and determine the maximum pixel value on the center ramp using the level control. Set level control to half of the maximum CT pixel value. Utilizing the electronic ruler, measure the width of each ramp.

(4) Repeat steps 2 and 3 above while varying the slice thickness from a maximum to a minimally used clinical setting. Save all annotated images.

e. Interpretation of Results:

(1) Determine the sensitivity profile width for each ramp section at each slice thickness tested.

(2) Refer to manufacturer's specifications for evaluation. In the absence of specifications, the measured profile width should be within ± 10 percent or ± 1 mm at the nominal slice width.

18. Slice Dose

a. Purpose: The surface slice dose should be established during acceptance testing to ensure that manufacturer's specifications are not exceeded.

b. Regulations: Refer to manufacturer's specifications.

c. Equipment: Phantom and TLDs or ready pack film.

d. Procedure:

(1) Place TLDs or ready pack film on a phantom to collect radiation from the scanned slices. A series of contiguous slices and single slices (separated by sufficient distance to reduce scatter) should be evaluated.

e. Interpretation of Results:

(1) TLDs should be read and recorded. Film should be evaluated using a scanning densitometer and H&D curve developed for the specific scanner kVp and film developer used. The manufacturer should be contacted if the surface slice dose is greater than manufacturer's specifications.

19. Scatter

a. Purpose: To establish and maintain control of the scatter pattern created by the CT scanner.

b. Regulations: Refer to manufacturer's isodose area plot for interior room measurements. Exterior room measurements should be less than 100 mrem per year for the general public.

c. Equipment: CTDI body phantom and electrometer with large (180 sq cm) probe.

d. Procedure:

(1) Center the CTDI phantom in the gantry opening and width of table. Place the probe at the first position to be evaluated. Scan under highest technique clinically used (1 slice) for body mode with the largest slice thickness. Record the electrometer reading. Move the probe to the next location and repeat the procedure.

e. Interpretation of Results:

(1) Exterior walls should not exceed the general public dose limit of 100 mrem per year.

(2) If doses within the room are significantly greater than the expected isodose values provided by the manufacturer a service engineer should be contacted.

20. Radiation Protection and Safety (under construction)

21. MSAD (formerly CTDI)

a. Purpose: To determine the radiation dose to tissues under different CT scan conditions.

b. Regulations: Manufacturer's specifications or section e. below.

c. Equipment: CTDI phantoms (head and/or body) and electrometer with CT probe.

d. Procedure:

(1) Place head CTDI phantom (16 cm phantom) in the patient head holder. Align the phantom so that the center hole coincides with gantry isocenter (using electronic grid) and the slice plane coincides with the center of the ion chamber sensitive volume.

(2) Align holes so that a hole is upper most at the "12 o'clock" position (this should also place holes at the 3, 6 and 9 o'clock positions).

(3) Scan the phantom using a 10 mm slice width. Look at the image to see if phantom is aligned; realign phantom, if necessary. Tape or secure phantom when aligned.

(4) Place ion chamber in the center hole, aligning the center of the sensitive volume with the scan plane laser,

(5) Place electrometer in exposure mode. Using standard head protocol, measure integrated exposure.

(6) Move chamber to the 3, 6, 9, and 12 o'clock positions. Repeat the measurements for each position.

(7) Repeat step (4) through (6) using different slice widths, kVps and mAs settings as necessary.

(8) Repeat the entire procedure using the body phantom, standard abdominal protocol and abdominal protocol variations as necessary.

(9) During acceptance testing, the head phantom may be scanned using abdominal protocol variations in addition to conventional scans using the abdominal phantom. These data can be used as a baseline to compare subsequent MSAD measurements using the head phantom only.

e. Interpretation of Results:

(1) Separate surface and isocenter exposure measurements should be calculated to provide the best data base for later use in dose estimates.

(2) Calculate MSAD in acrylic from exposure using the relationship:

MSAD = E x K x L/T x 0.78

where L = effective length of ion chamber
K = chamber energy correction factor (from calibration certificate)
E = temperature and pressure corrected exposure (R),
0.78 = Rad/R conversion factor (for acrylic).
T = nominal slice width (variable)

(3) CTDI is defined as:

$$CDTI = \frac{1}{nT} \int_{-7T}^{+7T} D(z)\,dz$$

where (n) is the number of slices per scan, T is the selected slice width, D(z) is the dose at point "z" on any line parallel to the rotational axis for a single scan. Quantitatively CTDI is the average dose over an interval of width "T" equal to the selected slice width, at a point (x,y) in the plane of the middle slice of a series of 14 scans.

(4) MSAD and CTDI are identical if the ion chamber active length used to measure MSAD is equal to 14 slice thicknesses and the interval between

slices equals the slice width. When the scan increment differs from the slice width, MSAD and CTDI are related as:

$$MSAD = \frac{T}{Z} \times CTDI$$

where T = selected slice width
Z = interval between slices

The equation does not hold if Z=0 or if Z>>T.

With thicker slices, MSAD tends to underestimate CTDI;
with thinner slices, MSAD overestimates CTDI.

(5) Compare MSAD with manufacturer's CTDI specifications. In the absence of specifications, the AAPM recommends that MSAD should agree to within + 20% of the manufacturer's CTDI target value.

22. Beam Quality

a. Purpose: To establish and verify the half value layer at clinically used kVp settings.

b. Regulations: Refer to manufacturer's specifications.

c. Equipment: Electrometer with CT probe and at least 10 mm aluminum.

d. Procedure:

(1) Ensure that the CT tube has been fixed in one location, preferably the top. This may require service engineer assistance.

(2) Place probe at isocenter, scan using largest slice thickness. Record electrometer reading.

(3) Place 4 mm aluminum within beam with good geometry. Repeat scan and record electrometer reading.

(4) Repeat procedure increasing aluminum until half value layer is reached.

(5) Repeat initial measurement to ensure that techniques and geometry have not been altered during procedure.

(6) Repeat for other kVp settings.

e. Interpretation of Results:

(1) If half value layer significantly exceeds manufacturer's specifications a service engineer should be contacted immediately. Excessive HVLs will reduce CT tube life.

23. Hard Copy Output Device (under construction)